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LIFE CYCLE MANAGEMENT (LCM)

Rethinking a product and its function using LCA—experiences of New Zealand manufacturing companies

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Abstract
Purpose It has been recognised that life cycle assessment (LCA) has a role in framing problem situations in environmental management. Yet relatively few studies have investigated whether the use of LCA does actually lead to the reconceptualisation of product systems as opposed to answering predefined questions. This paper discusses the experiences of six manufacturing firms that commissioned LCA studies as part of a life cycle management project managed by Landcare Research in New Zealand.
Methods The initial goal and scope of the study was developed by each company's representative in a workshop that was organised as part of the LCM project. The scope for three of the studies was subsequently redefined by the LCA specialists at Landcare Research and agreed with senior managers at the company. The LCA specialists undertook the LCA studies and presented the results to the companies.
Results and discussion A significant reconceptualisation of the product system took place in three of the six LCA studies. This reconceptualisation would not have taken place if the scope of the LCA studies had been restricted to address the questions originally asked by the companies. The three companies showed some resistance to expanding the scope.
Conclusions Use of LCA can lead to reconceptualisation of product systems by companies and quite different priorities for improvement options. Initial resistance to expanding a study's scope may be (partially) overcome by data collection activities and informal discussions between the LCA specialist and company staff during the process of undertaking the LCA study.

Keywords Life cycle assessment · Life cycle management · Goal and scope definition

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1 Introduction

It has been recognised for a long time that life cycle assessment (LCA) can be used not only for direct decision support but also as a tool for raising awareness, for learning and/or for reconceptualising the way we think about product systems (e.g. Baumann 1998; Cowell 1998; Baumann and Tillman 2004). Ehrenfeld (1997) has described LCAs as "serving two distinct purposes: (1) to raise or frame questions (framing), and (2) to provide answers to previously raised questions (analysis)". Also, with respect to uses of LCA, Heiskanen (1999) suggests that LCA can be used in definitive, conceptual, and facilitative applications: definitive applications can be seen as direct decision support; conceptual applications as use of LCA to gain a shared perspective of a problem area; and facilitative applications where LCA data are provided or required from some actors in the supply chain to be used for "do-it-yourself" LCA studies. In two further papers, Heiskanen (2000, 2002) discusses the function of LCA in altering the "mental models" of managers about their companies' products, and extending their perceptions of responsibility beyond the usual company boundaries. Interestingly, both Ehrenfield and Heiskanen

argue that the more significant role of LCA lies in how it leads to reconceptualisation of product systems as opposed to its role in providing a quantitative representation of product systems to answer predefined questions. Heiskanen (2002) states that "the central role of LCA-based tools and models is not in solving problems, but in constructing problems in a distinctive way" (p 434) and, "If we want to evaluate the accomplishments of LCA, we should not only look at formal uses of the LCA tool" (p 427).

However, although numerous life cycle assessment (LCA) studies have been undertaken in the last 20 years, research on LCA has traditionally focused on methodological issues (Rex and Baumann 2007). Few papers investigate whether the use of LCA leads to the raising of awareness, learning and/or reconceptualisation of product systems as opposed to answering predefined questions.

From a company perspective, life cycle management (LCM) has emerged as an umbrella term to describe an integrated framework for managing the total life cycle performance of goods and services with the aim of realising more sustainable forms of production (Saur et al. 2003). LCM places a greater emphasis on the pragmatic application of life cycle thinking as opposed to undertaking detailed LCA studies (see, for example, Rebitzer and Buxmann 2005); indeed, the UNEP/SETAC guide to LCM states that LCA is not a mandatory tool for implementing LCM (Remmen et al. 2007, p 22). Although Rebitzer and Buxmann (2005) noticed that there is agreement that LCA plays a central role in LCM, there are very few published studies that examine the relative importance—or not—of undertaking LCA studies within a company LCM Programme (Rex and Baumann 2008).

This paper reflects on the experiences of six manufacturing firms that commissioned LCA studies as part of their involvement in a life cycle management project in New Zealand between December 2008 and December 2010. It focuses in particular on how the product systems under study in three of the companies were reconceptualised during the process of undertaking the LCA studies, resulting in both altered perceptions of the areas of environmental responsibility for the companies and different implications for improvement initiatives. For the three companies, the reconceptualisation process involved expanding the scope of the LCA studies to include additional downstream unit processes, i.e. redefining the system boundaries. Interestingly, there is very little guidance in the LCA handbooks and standards on how to define the appropriate scope for a study—apart from the injunction that the scope should address the goal of the study (e.g. ISO 14044, Section 5.2.1.1). Indeed, the earliest American LCA guides did not include "Goal and Scope" as the initial phase in an LCA study (Fava et al. 1991) or included it as an optional additional phase (Vigon et al. 1993). Reap et al. (2008, p.295) note, "more research is needed to provide clear practical guidelines, appropriate information, and tools to support boundary selection in LCA practice."

Section 2 describes the LCM project and the associated training programme undertaken by the six companies, and Section 3 summarises the process adopted for undertaking the LCA studies with the companies. Section 4 introduces the three companies where reconceptualisation of the product systems took place, and summarises how their LCA studies were originally developed plus the subsequent reconceptualisation process. The results of these three LCA studies are presented in Section 5 and the implications are discussed in Section 6.

2 The life cycle management project

The Life Cycle Management Project ("LCM Project") was initiated in 2008 by Landcare Research, a Crown Research Institute in New Zealand, and is managed by an LCM Project Team of Landcare Research staff and subcontractors with skills (both practical and academic) in organisational change and LCA/LCM. The purpose of the Project is to build capability among New Zealand manufacturing companies for product-orientated environmental management. As part of the LCM Project, a pilot LCM Training Programme was developed and delivered to six companies between 2008 and 2010; the companies were from the injection moulding, decorative furniture, outdoor timber decking, roofing, healthcare, and agricultural pesticide sectors. Each company nominated an LCM Champion responsible for integrating LCM into the company operations; this person took part in a series of workshops to learn about LCM, and was supported in developing and implementing an LCM Programme in his/her own company as part of the LCM Training Programme.

The different components of the LCM Training Programme are:

- LCM Workshops: nine workshops attended by the LCM Champions on the topics of LCM, Environmental Management Systems, LCA, product design, end-of-life management, supply chain management, green marketing, carbon foot-printing, and integration of LCM into everyday operations.
- Meetings with Senior Managers: senior managers, e.g., CEO or board level employees were directly engaged in the process through three meetings held with the LCM Champion and members of the LCM Project Team at critical points in the Programme.
- Development of an Environmental Management System (EMS): setting up an EMS for those companies that do not have one in place already through involvement in Enviro-Mark, a New Zealand environmental management certification organisation.

- Life cycle study: an LCA study of one of the company's products was undertaken by the LCA specialists in the LCM Project Team based at Landcare Research.
- Development of an LCM Programme: development and implementation of a Mission, Strategy, and Work Plan.

During the LCA studies, the scope for three of the six studies changed from an initial focus on the manufacture and delivery of the product to a wider product system that expanded the company's area of responsibility downstream in the value chain. This change of focus had not been anticipated, and was one of the most interesting outcomes of the LCM Training Programme. It led the authors of this paper to reflect on the role of LCA in company LCM programmes, and became the basis for the perspectives put forward here.

In particular, this paper focuses on how the scope of an LCA study may change (or not) during the process of undertaking a study, what this implies for improvement options, and the role—therefore—of LCA in reconceptualisation of product systems versus addressing predefined questions. Regarding the latter point, some reflections are offered on the relative effectiveness of LCA studies versus life cycle thinking in acceptance of reconceptualised product systems amongst company staff. Note that a detailed analysis of practical changes in each company after completion of the LCA studies is outside the remit of this paper. Rather, its focus is on the essential step that must be taken prior to proceeding on to implementation of practical change(s) (in the absence of legislative requirements): recognition of the legitimacy of a reconceptualised product system by company stakeholders (as discussed by Cowell (1998, p.197–207)).

3 Process for undertaking the LCA studies

Building on earlier discussions, the goal, objectives, and system boundaries for each LCA study were formally defined at the third workshop in the LCM Training Programme; they were developed by each LCM Champion supported by the LCA specialists from the LCM Project Team who attended the workshop. Based on notes from the workshop, the initial Goal and Scope for each study was subsequently written up by the LCA specialists and sent to the LCM Champion for verification. The initial Goal and Scope was recorded in a company dossier that also included the Mission, Strategy and Work Plan for the company as these were developed during the LCM Project. The dossier was updated at intervals during the LCM Project, and each version was kept by the LCM Project Team as evidence of progress.

For three of the companies, the scope for the LCA study did not change between the beginning and end of the study:

- The roofing company was interested in the environmental impacts of its tiles from initial production of the tiles through use to end-of-life management (including options for recycling).
- The healthcare company wanted to know about the environmental impacts of its honey product from production through to delivery to the consumer—including end-of-life management of the packaging.
- The agricultural pesticide company wanted to identify the environmental hotspots associated with the life cycle of one of its pesticides, including the use phase.

However, for the three other companies the scope for the LCA study changed as the study progressed and resulted in quite different improvement options from those initially expected. Section 4 provides more details about each of these three LCA studies, including the company's initial motivations for carrying out the study, the initial goal and scope, and the reconceptualised scope. The results of the impact assessment for both the initial and the reconceptualised scope for the three studies are presented in Section 5.

The LCA specialists in the LCM Project Team undertook the LCA studies over 6 to 18 months; during this time, one of the LCA specialists worked intensively with each company, making at least one site visit for data collection and regularly communicating with the LCM Champion by telephone and e-mail to collect data. In the early stages of this process, the LCA specialists discussed amongst themselves the appropriateness of the initial scope of each study as recorded in the company dossier. On reflection, the LCA specialists felt that, for three of the companies, the scope could be expanded to include more downstream processes in the product life cycle in order to reflect a more comprehensive life cycle perspective. This reconceptualisation of the scope was initially raised by the LCA specialists with the LCM Champion and it was subsequently discussed at a meeting with company senior managers. Despite continued reservations about the expanded scope amongst company staff, the LCA specialists undertook the more comprehensive life cycle studies.

Once completed, the results of each LCA study were presented to the LCM Champion and at least one senior manager in each company, and requests for clarification were addressed before production of the final LCA study reports.

Each LCA study was undertaken at a fairly detailed level, although some data had to be estimated due to time restrictions. Product system-specific data were collected for: materials and energy used directly in manufacturing processes under the direct control of the companies, most transport distances both upstream and downstream of the manufacturing site, and energy sources and electricity mixes for

electricity used throughout the product life cycle. Estimates were made for specific transportation modes and all truck datasets were chosen for the EURO 3 standard for consistency; size of the trucks and assumptions of distances were looked at in a case by case basis.

Data on the inputs and outputs associated with different materials and energy sources were taken from the ecoinvent database. An electricity dataset was compiled for New Zealand taking the average mix for the year 2008 and specific emissions from the literature in relation to geothermal electricity generation. Modelling was undertaken using the SimaPro 7 software, and impact assessment used the CML 2 baseline 2000 method taking into account the standard suite of categories: abiotic depletion, acidification, eutrophication, global warming, ozone layer depletion, human toxicity, freshwater aquatic ecotoxicity, marine aquatic toxicity, terrestrial toxicity, and photochemical oxidation.

4 LCA studies involving reconceptualisation of the product system

4.1 Company 1: Hot runner systems

4.1.1 Company and product description

Company 1 specialises in hot runner systems that are used for plastic injection moulding in applications ranging from electronics to packaging to automotive parts. A hot runner system, which consists of a steel manifold, temperature control system, and nozzles, injects molten plastic into a mould. The main alternative technology for this application is cold runner systems, which have lower energy consumption than hot runner systems but generate larger quantities of waste plastic. The company wanted to investigate the environmental impacts associated with one of its products; at the beginning of the LCM Project the company's concerns were with the operational suitability of the hot runner systems for possible future substitution of bio-plastics in place of fossil oil-based plastics, and transportation and energy use in the supply chain. However, the operational suitability of the hot runner systems for use with bio-plastics was considered by the LCA specialists to be outside the remit of the LCM Project and was excluded from further analysis.

4.1.2 LCA study

The goal of the study was initially defined as to investigate the environmental impacts associated with production and delivery of a manifold, including nozzles, to the customer. The LCM Champion wanted to "find out where we stand". A functional unit was initially defined by the LCM Champion in the company as "production and delivery of an 'H' shaped hot runner to the customer".

4.1.3 Reconceptualisation of product system

In development of the initial Goal and Scope at the LCM Training Programme workshop, the focus was on production of the hot runner and its delivery to market. However, in subsequent discussions between the LCA specialists, it was felt appropriate to redefine the scope to include the use phase as this expanded system would provide a better perspective on the potential benefits of the hot runner system relative to its competitors. The product system was therefore expanded to include the production and use of plastic, electricity consumption during the use phase of the plastic product, and post-use plastic disposal.

The hot runner system is linked to an injection moulding machine (which has the highest energy use in production of moulded plastic); although the injection moulding machine is not sold by the company, its energy use was included in the redefined study. The scenario modelled was for caps produced in China as this is one of the main markets for the company's products; landfilling of the plastic caps after use was also included (landfilling is the most common form of waste management in China). The functional unit was therefore redefined as, "production, using an 'H' shaped hot runner, and use of plastic caps in China".

4.2 Company 2: Decorative lampshades

4.2.1 Company and product description

Company 2 is a decorative furniture company. For the LCA study, it wanted to investigate the environmental impacts associated with one of its lampshades. The lampshade is made from strips of polycarbonate and bamboo joined together with aluminium rivets. The product is assembled in New Zealand, packed into cardboard boxes together with electrical cables and sockets, and sent by aeroplane to market.

The company was particularly interested in: (a) identification of the environmental hot spots in the life cycle of the lampshade in order to improve the design of future products, and (b) evaluation of the environmental consequences of transporting a flat-packed lampshade for assembly at the final destination as opposed to a lampshade assembled at the manufacturing site in New Zealand and transported as an assembled product. The company's environmental concerns at the beginning of the project were about their manufacturing process, transport to market, and material selection.

4.2.2 LCA study

The goal of the study was to investigate the environmental impacts associated with production of a lampshade and its transport to market. A functional unit was defined as,

"production and delivery of one lampshade to market". A baseline scenario was developed to investigate the environmental impacts associated with assembled lampshades sent to Australia (one of the company's main markets for lampshades), and a scenario was modelled for the alternative flat-packed lampshade.

4.2.3 Reconceptualisation of product system

In development of the initial Goal and Scope at the LCM Training Programme workshop, the focus was on production of the lampshade and different options for its transportation to market. However, in subsequent discussions between the LCA specialists, it was felt appropriate to redefine the scope to include electricity during use. The functional unit was therefore redefined as "lighting provided by a lampshade for ten years". The redefined product system now included the use phase in Australia, and accounted for electricity used during the lifetime of the lampshade.

4.3 Company 3: Outdoor timber decking

4.3.1 Company and product description

Company 3 specialises in outdoor use of high quality timber for domestic and commercial buildings. The decking is made from New Zealand grown timber that is harvested, treated, and manufactured into decking by the company. After being treated, shaped and coated, the timber is packed and shipped to intermediary distributors who sell the product on into the marketplace. The company wanted to investigate the environmental impacts associated with its timber decking product; at the beginning of the LCM Project, the company's environmental concerns were about the waste management of shavings, packaging end-of-life options, energy use in the transportation, and maintenance regimes.

4.3.2 LCA study

The goal of the LCA study was defined as to investigate the environmental impacts associated with the timber decking product and to identify improvement possibilities with respect to the environmental profile of the product. A functional unit was initially defined as "15 m^2 timber decking that lasts 25 years". The baseline scenario was developed to investigate the environmental impacts associated with a 21-mm-thick plank timber decking, manufactured in New Zealand, exported, and sold in one of the company's main markets, France. The company was also interested in investigating different maintenance scenarios as part of the study: (a) re-coating in line with the company's recommendations; and (b) no re-coating or any other maintenance activities.

4.3.3 Reconceptualisation of product system

In development of the initial Goal and Scope at the LCM Training Programme workshop, the substructure for the timber decking was recognised as being relevant for inclusion in the LCA study, as were maintenance activities throughout the life time of the decking. However, the LCM Champion omitted both these aspects when defining the functional unit and setting system boundaries for the LCA study as the focus moved to the timber decking itself and to activities that were under the direct control of the company. It should be noted that neither the substructure nor the chemical required for maintenance are supplied by the company, although they are, of course, required in order to use and maintain the timber decking product.

In subsequent discussions among members of the LCA specialists, it was felt appropriate to redefine the scope to include both the substructure and the decking maintenance. The substructure consisted of timber joists and piles, bolts, nails, and screws.

As a result of including these additional activities, the functional unit was redefined in agreement with the company LCM Champion to be, "Provision, placement and use of decking for an area of 15 m^2 for 25 years in France".

5 Results of LCA studies

5.1 Company 1: Hot runner systems

The LCA results in Fig. 1 show that, for the initial scope (modelling only the production and delivery of the manifold), air freighting the final product ("product transport" in Fig. 1) is the dominant life cycle stage for several impact categories, followed by production of raw materials (mainly steel for the manifold and nozzles).

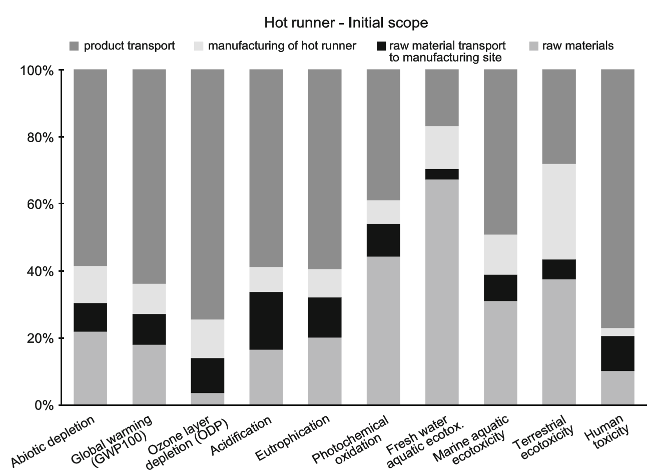

Fig. 1 Impact assessment results using initial scope for the hot runner system (production and delivery of machine)

In order to model the reconceptualised system (which included electricity consumption by the hot runner system during use, production of plastic to produce plastic caps, and landfilling of the caps at end-of-life), it was necessary to estimate the lifetime of the machine. As no precise information was available, a scenario was modelled assuming the machine was used for 100 shifts each lasting 10 h, which is a low life expectancy for the machine. Figure 2 shows the results for the reconceptualised system in China; on this figure, the scale is set so that "1" represents the impact assessment results for the initial scope (and note that the axis is broken to represent the much larger freshwater aquatic ecotoxicity category result). It can be seen that the initial scope results are very small compared with the reconceptualised system results for every impact category.

Figure 2 also shows that production and disposal of the plastic has a much higher impact in several categories than electricity consumption during use of the machine. It can be concluded, therefore, that the production and delivery of the manifold will always be insignificant compared with the impacts of the plastic because a conservative assumption was made about the lifetime of the machines; a more realistic assumption about the lifetime of the machines would further accentuate this result.

Thus, for the hot runner system, expanding the scope from "production and delivery of an 'H' shaped manifold to the customer" to "production and use of plastic caps" highlights (a) the relatively insignificant contribution of production and transport of the machine compared with the use phase, and (b) the relatively significant contribution of plastic production and disposal compared with electricity consumption during the use phase for the majority of impact categories.

In summary, the results for the original study suggest a focus for improvement initiatives around product transport and production of steel for the manifold. However, the reconceptualised product system indicates that, at least for the scenario modelled (plastics moulded in China), the focus should be initiatives to increase efficient operation of the hot runner system and injection moulding machine in order to minimise plastic wastage and electricity use.

5.2 Company 2: Decorative lampshades

For the decorative furniture company, the results of the LCA study for the production and delivery of an assembled lampshade to Australia are shown in Fig. 3. Transport-related life cycle stages (delivery of raw materials to production site and transport of the lamp to Australia) accounted for more than one quarter of the impacts of the lampshade in all impact categories, and at least half of the impact in all impact categories except the ecotoxicity categories.

However, for the reconceptualised system where the product system is expanded to include electricity in use (shown in Fig. 4) the inclusion of electricity consumption results in much higher impacts. For the scenario modelled here (use for 1 h a day for 10 years), the life cycle impacts range from approximately 30 to 300 % higher compared with the impacts for the lampshade using the "initial scope".

Expanding the system boundary to include electricity consumption at the use phase therefore suggests that the focus of attention for improvement initiatives should be electricity consumption during use as well as product transport to the consumers. Of course, this result is dependent upon the electricity mix in the country where the lampshade is used.

5.3 Company 3: Outdoor timber decking

The results of the LCA study of timber decking are shown in Fig. 5. Figure 5 shows the results for the product system excluding the timber sub-frame. It can be seen that coating and maintenance, and product transport life cycle stages

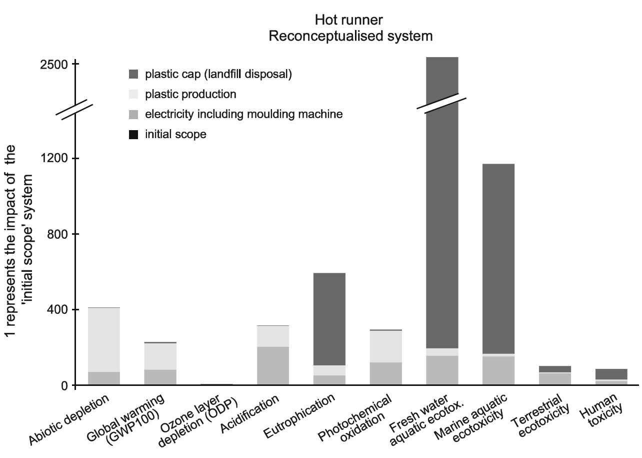

Fig. 2 Impact assessment results for reconceptualised product system for hot runner system (production, delivery, and use of machine; production and use of plastic caps in China)

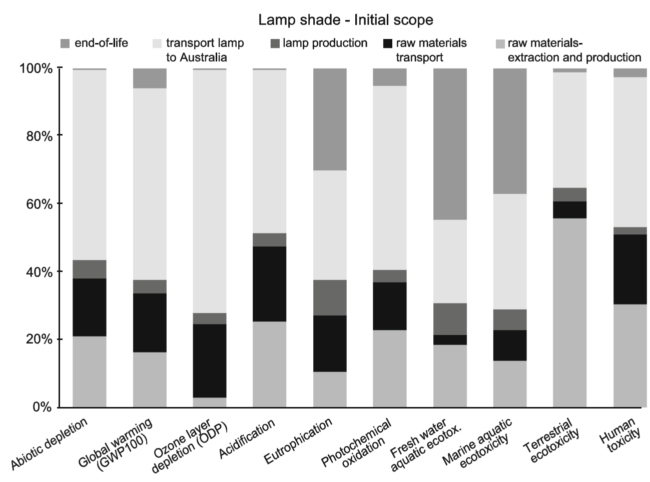

Fig. 3 Impact assessment results using initial scope for the lampshade (production, delivery, and end-of-life management)

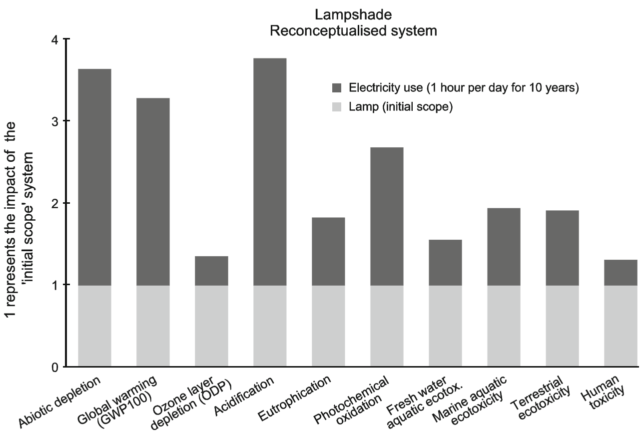

Fig. 4 Impact assessment results for the reconceptualised product system for the lampshade (production, delivery, electricity use, and end-of-life management)

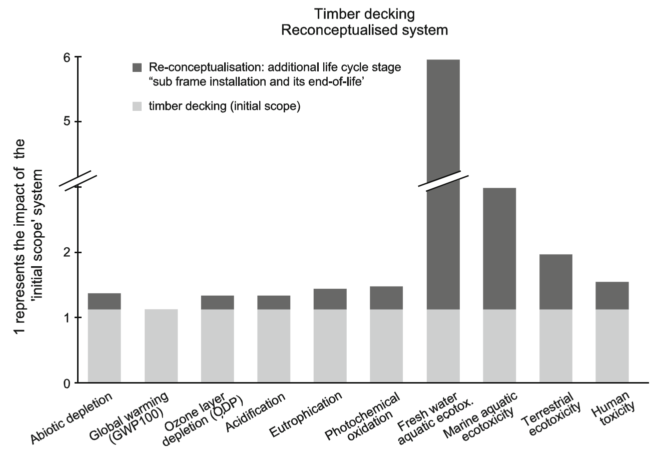

Fig. 6 Impact assessment results for reconceptualised timber decking (timber production and processing, transport, maintenance, and end-of-life, plus sub-frame installation and end-of-life)

together account for more than 50 % of the impacts in most categories.

Figure 6 shows the results for the product system including the timber sub-frame. It can be seen that, although initial coating (which happens at the production site), maintenance re-coating, and product transport still play import roles in the life cycle of the timber decking, there is a large increase in all the ecotoxicity categories.

These toxicity results are related to the type of sub-frame material used and how it is treated at end-of-life. Note that a conservative approach was used for this study: it was assumed that chromium-treated wood was used for the sub-frame and incineration at end-of-life, which is likely to be a worst-case scenario.

The results indicate that inclusion of the sub-frame can indicate quite different improvement options for the product system. Excluding the sub-frame, the improvement focus is likely to be on transport of the decking, and coating and maintenance options. However, if the sub-frame is included, the type of wood used in the sub-frame becomes relevant because its treatment may make a relatively large contribution to the toxicity impact categories; other types of impacts could also turn out to be relevant, such as the type of forest management for the sub-frame wood.

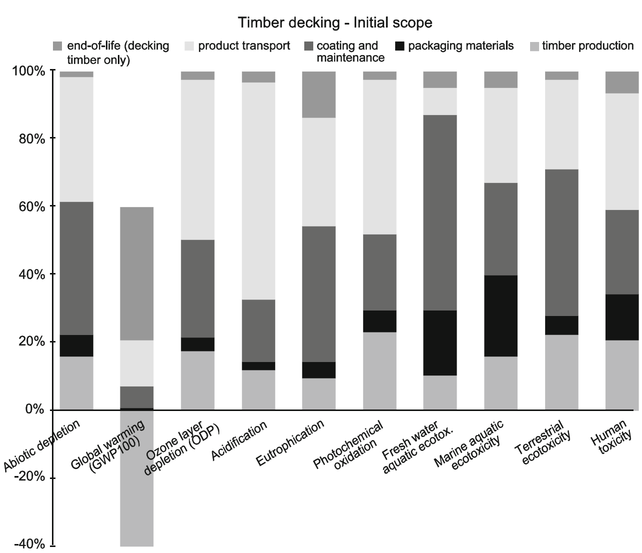

Fig. 5 Impact assessment results using initial scope for the timber decking (timber production and processing, transport, maintenance, and end-of-life)

Thus, although the sub-frame is not part of the product sold by the case-study company, it is required by customers in order to use the company's decking product and, depending on its constituent materials, it can make a significant contribution to the life cycle impacts of the product system. Therefore, the reconceptualised system suggests the company could, for example, set minimum requirements for the sub-frame suppliers' environmental profile.

6 Discussion

For three of the six companies involved in the LCM Project, the process of undertaking the LCA study led to reconceptualisation of the product systems in addition to addressing the predefined questions. For the other three companies, a wider scope was defined by the LCM Champion at the outset of the LCA study. The ready adoption of the wider scope by these three companies may be related to: (a) the more straightforward product systems analysed in these three companies (e.g. production and use of a pesticide with its associated packaging as opposed to production of a decorative lampshade plus the additional function of light provision from a lightbulb in the lampshade); and/or (b) the fact that the companies did not expect that the inclusion of secondary activities (such as production of sugar used for supplementary feeding of bees in the honey LCA study or

inclusion of the timber roof frame in the roof tiles LCA study) would make a significant difference to the final LCA study results.

The three studies described in Sections 4 and 5 indicate that reconceptualisation of a product system during the process of undertaking an LCA study can lead to identification of quite different environmental hotspots. For the hot runners, the reconceptualised product system highlighted the importance of reducing plastic waste during injection moulding. For the decorative lampshades, the reconceptualised product system suggested an additional focus on electricity consumption during use of the lampshades. For the outdoor timber decking, the toxicity results for the reconceptualised product system highlighted the potential contribution of the sub-frame (depending upon the treatment process used for the sub-frame wood).

The three companies whose LCA studies involved reconceptualisation of the scope exhibited a certain degree of resistance to redefining the system under analysis to include additional life cycle stages and processes. The LCA specialist was able to justify the expanded scope to the LCM Champion and to other company staff (where relevant) in the early stages of the study by explaining that the company's initial (predefined) questions would still be addressed in the study and by reiterating that the study was for information only, and that the company did not have to act on the results. It is worth noting here that the LCM Training Programme and the LCA study were provided free of charge to the companies; in a sense, there was a degree of obligation on the part of the companies to agree to ideas put forward by the LCM specialist. In a commercial situation, it might not have been so easy for the LCA specialist to redefine the scope for the LCA study because she would have been obliged to prioritise addressing the company's articulated concerns, i.e. the predefined questions.

The main reasons identified for the resistance experienced during the LCA study were: (1) unfamiliarity with the concept of life cycle thinking and therefore a lack of understanding about its role being wider than assessment of just the product sold by the company, and (2) a perceived lack of control over the additional processes downstream in the supply chain that became part of the expanded product system (e.g. electricity use for the lamp, sub-frame material for the decking).

Regarding point (1), the three companies discussed in this paper spanned a range from one with an initial very low level of awareness about life cycle thinking to one with previous LCA knowledge. It was observed that the company with previous LCA knowledge moved more quickly from resistance to recognising the reconceptualised system as a legitimate way of viewing its product system.

Regarding point (2), all the companies indicated, at least initially, that they did not believe they could influence the use phase. Therefore, there was a preference to focus on in-house improvements such as raw material selection, its source or its optimal use. The belief about a lack of influence on the downstream supply chain can mainly be attributed to the companies being small to medium sized and, to a certain extent, to being physically distant from their overseas markets.

As noted in Section 1, little attention has been paid to the role of an LCA study, as opposed to life cycle thinking, in reconceptualisation of product systems. Heiskanen (2000) suggested that, in the case of Finnish companies, new perspectives among companies' managers (such as increased awareness of the transportation and use phases, or impacts in different locations or in the future) were inspired by life cycle thinking rather than directly informed by an actual LCA study. However, in the LCM Project, it was the impression of the LCA specialists that acceptance of new perspectives in the companies (i.e. the expanded scope of the product systems) was facilitated by the process of undertaking the LCAs and collecting inventory data. For example, the hot runner and decorative furniture companies were asked to provide data on the life time of their products and energy consumption in the use phase, while the decking company had to provide information on the distance the sub-frame would be transported. This process of data collection facilitated informal discussions between the LCM Champion and the LCA specialist about the scope of the study over a period of several months, and therefore acted as an awareness-raising exercise for this person. The other activities in the LCM Project, such as the LCM workshops, also contributed to awareness-raising amongst company staff over the same time period. The roles of each of these different activities in developing acceptance amongst company staff of the legitimacy of the extended scope for the LCA studies was not analysed in detail. However, the process of undertaking an LCA study over a period of time, and involving the company staff (in particular, the LCM Champion) in that process, did facilitate rethinking of the product system and acceptance of an expanded scope amongst those company staff.

As a result, by the time the final results were presented to the LCM Champion and a senior manager, there was greater acceptance of the legitimacy of the extended scope in all three LCA studies. For example, a senior manager from the decorative furniture company commented at the meeting where the LCA results were presented, "The use phase was something that I had not thought about, that came up [during discussions] with the LCA practitioner (…). Being a manufacturer, we probably did not consider [the use phase] very much because we are looking at what we are making, in terms of getting the right material and getting rid of it in the end", and, "What I am reading from this [LCA results] is that we can significantly change the impact of the light, say, putting a LED bulb in rather than the compact bulb".

The critical phases for generating acceptance by the LCM Champion and company senior managers of this reconceptualisation in the LCA occurred at:

- Goal and Scope Definition: each LCM Champion defined the initial Goal and Scope for the LCA study at the third workshop in the LCM Training Programme. Having been introduced to life cycle thinking and Environmental Management Systems in the two previous workshops, and LCA in the first part of the third workshop, the LCM Champions were enthusiastic about applying it to their companies' products. However, as noted elsewhere in this paper, some of them interpreted life cycle thinking more narrowly than others, and so a true 'cradle to grave' approach was not evident in definition of the scope for the LCA studies at that time.
- Inventory Analysis: as the LCA specialist began to collect data for the LCA study, a certain level of resistance was experienced from some of the LCM Champions to providing data related to processes that were considered "out of scope". This led to informal discussions on the expanded scope between the LCA specialist and the LCM Champion.
- Presentation of draft LCA results: for some of the LCA studies, the LCA specialist was questioned by the company staff about the relevance of including certain life cycle stages or impact category results and this led into to discussions about the legitimacy of the expanded scope.

7 Conclusions

In conclusion, to return to the original question about the role of LCA in reconceptualisation of product systems versus addressing predefined questions, a significant reconceptualisation of the product system took place in three of the six LCA studies undertaken with the six companies in the LCM Project—where "significant" is determined based on changes in the environmental hotspots identified for each product system. This reconceptualisation would not have taken place if the scope of the LCA studies had been restricted to address the questions originally asked by the companies. Arguably, the reconceptualisation could have taken place through the structured application of life cycle thinking to the product systems as opposed to undertaking LCA studies—or through use of simplified life cycle tools such as the matrices used in Design for Environment initiatives. However, the informal discussions between the LCA specialist and company staff that accompanied the process of defining the scope for each LCA study, collecting data, deciding on the number of impact categories to be addressed at Impact Assessment, and so on, did contribute to building acceptance of the legitimacy of the reconceptualised product systems with company staff. As such, the process of defining an LCA study's scope in cooperation with the commissioners of that study deserves further consideration in future research.

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